InSight: Mission to Mars

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Abstract— ***The InSight Mission will uncover the geophysical characteristics of Mars and use comparative planetary geophysical techniques to better understand the formation and evolution of Mars and thus by extension other terrestrial planets. The InSight spacecraft has heritage from the 2001 Mars Lander which was used for the Phoenix mission and from more modern missions for the spacecraft avionics. The mission also carries several instruments and sensors designed to achieve the science mission objectives. International partners contributed several of these sensors. This paper will describe the InSight mission and science objectives as well as some of the changes made to the mission when the launch date was postponed from 2016 to 2018.***
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1. PROJECT DESCRIPTION

The InSight (Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport) mission is in the Discovery portfolio of the NASA Planetary Science Division within the Science Mission Directorate. The mission selection was made in 2012 as part of the competitive process used for Discovery missions and is managed by Jet Propulsion Laboratory (JPL) for NASA as part of the Planetary Missions Program Office portfolio. InSight was initially intended to launch in 2016, but was delayed to 2018 due to one of the key instruments not being delivered.

The InSight mission science objectives are to investigate the fundamental processes of terrestrial-planet formation and evolution by performing the first comprehensive surface-based geophysical investigation of Mars. It will provide key information on the composition and structure of an Earth-like planet that has gone through most of the early evolutionary stages of the Earth. Thus, the traces of this history are still contained in the basic parameters of the planet: the size, state and composition of the core, the composition and layering of the mantle, the thickness and layering of the crust, and the thermal flux from the interior [1].

InSight has a focused set of three investigations utilizing two instruments and a spacecraft subsystem. The investigations use seismology, precision-tracking and heat-flow measurements to unlock the secrets of the Martian interior. The knowledge provided by the InSight mission will substantially advance understanding of the formation and evolution of terrestrial planets.

2. SYSTEM DESCRIPTION

InSight investigates the Martian interior using seismic sources (tidal, Marsquakes, impacts, etc.), rotational, and thermal measurements. The two instruments are deployed on the surface using a robotic arm. Once deployed and commissioned the instruments will gather data for a Marian year (26 Earth Months).

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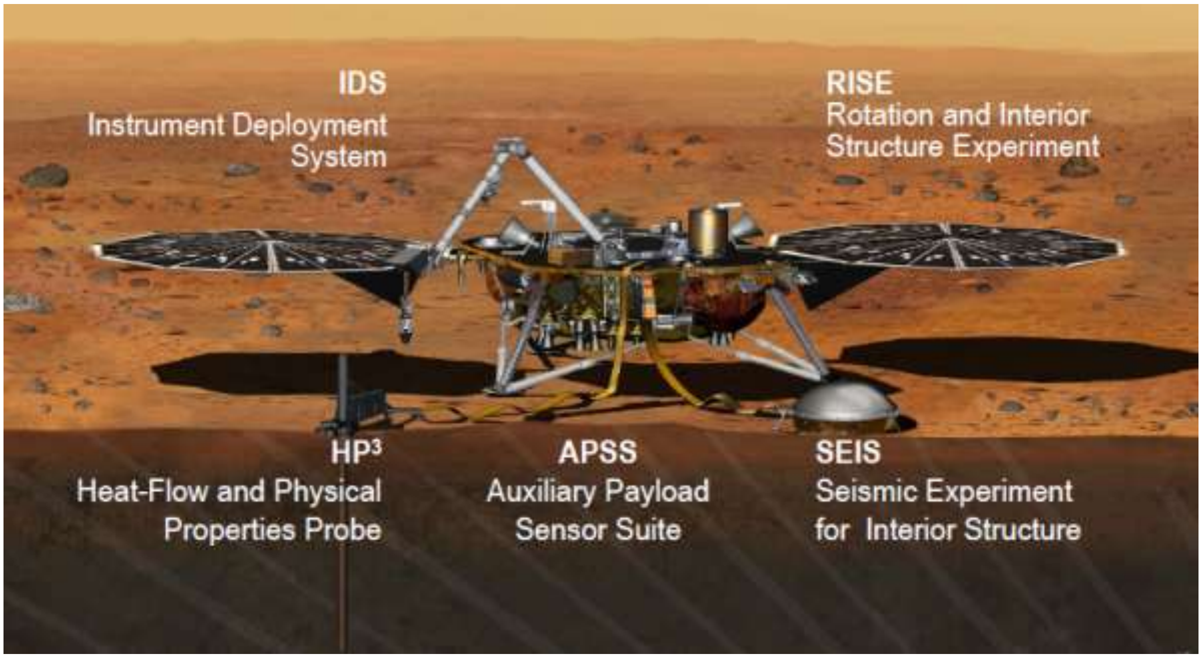

Figure 1: InSight Payloads

InSight was developed using heritage from past missions for the Flight System, Operations, and Mission Design. The Flight Systems is being designed, built, and tested by Lockheed-Martin Space Systems Corporation (LM) in Denver Co. The Flight system design builds off past successful missions. The spacecraft system is based on the Phoenix flight system, upgraded with Juno/Gravity Recovery and Interior Laboratory (GRAIL) avionics. JPL manages the mission using the same approach to the JPL/LM partnership that delivered Mars Reconnaissance Orbiter (MRO), Phoenix, Juno, and GRAIL. JPL manages delivery of the international payloads and directed developed and delivered the remaining payload elements [2] .

The payload includes six elements:

Seismic Experiment for Interior Structure (SEIS): Three-axis seismometer, to measure seismic waves traveling through the interior. Uses two different type of sensors (broad band & short period) built with different technology.

Rotation and Interior Structure Experiment (RISE): Radiometric geodesy, to determine precession & nutation of the planet's rotation axis. Measurement made with the spacecraft telecom hardware.

Heat Flow and Physical Properties Package (HP3): Subsurface heat probe, to measure the heat flux from the interior.

Instrument Deployment System (IDS): Robotic arm and two cameras: to map workspace, deploy SEIS elements and HP3 to the surface. Uses upgraded residual flight robotic arm hardware from Mars Surveyor Project 2001 (MSP01), and residual upgraded MER flight cameras.

Auxiliary Payload Sensor Suite (APSS): The APSS is a suite of environmental sensors to support the SEIS investigation by allowing correlation of environmental factors to the observed measurements.

Laser Retro-Reflector for InSight (LaRRI): The Laser Retroreflector consists of corner cube retroreflectors. It will facilitate Mars geophysics as well as tests of general relativity investigations by a future TBD orbiter.

These payloads are shown on the InSight Lander in Figure 1.

2.1 Science Requirements

The science objectives addressed by the InSight mission have been a priority for decades within the science community [3]. Specifically, InSight provides first ever geophysical exploration of the Martian interior using seismic and thermal measurements and rotational dynamics, providing information about the initial accretion of the planet, the formation and differentiation of its core and crust, and the subsequent evolution of the interior. The InSight science goals are simply stated [4]:

1. Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars
2. Determine the present level of tectonic activity and impact flux on Mars

From these goals flow a fundamental set of baseline science objectives:

• *Determine the size, composition and physical state of the core*
• *Determine the thickness and structure of the crust*
• *Determine the composition and structure of the mantle*
• *Determine the thermal state of the interior*
• *Measure the rate and distribution of internal seismic*

activity
• *Measure* the rate of impacts on the surface

2.2 MISSION DESIGN

InSight relies on the knowledge gained from past successful missions developed for landing on Mars in the design of the mission, Further, InSight flight systems utilizes the specific knowledge gained from the Phoenix (PHX) mission for the EDL design. InSight structures and landing systems and architecture are nearly identical to the PHX mission. Because of the significant hardware and system design heritage to the PHX mission, the mission design for cruise and EDL is almost identical to PHX.

2.2.1 Launch/Cruise

InSight will launch from Vandenberg Air Force Base (VAFB) aboard an Atlas 401 rocket in May 2018. The injection capability of the rocket allows for a Type-I ballistic trajectory yielding a 6.5-month transfer to Mars See Figure 2: InSight Trajectory). EDL at Mars directly follows the Phoenix design and operations scenario. InSight has chosen a landing site in Elysium Planitia, which meets both engineering and science requirements. Following landing and instrument deployment to the Martian surface, the mission begins a 1-Mars-year monitoring phase of routine, repetitive, continuous data collection. It communicates with Earth via orbiting assets nominally twice per sol [5]

InSight will be launched into a ballistic, Type-1 trajectory to Mars during the 2018 Earth-Mars launch opportunity shown in **Error! Reference source not found.**. The cruise activities are similar to a typical Mars mission and are designed to achieve the proper entry flight angle to support the entry, descent and landing phase of the mission.

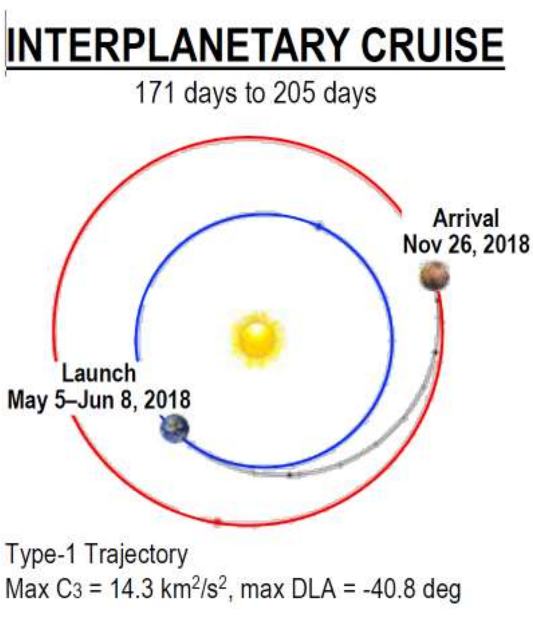

Figure 2: InSight Trajectory

2.2.2 Entry, Descent and Landing [6]

The EDL phase begins at Entry-3 hr. The first event is the final update of EDL FSW parameters, followed by spacecraft entry-state initialization at E-10 min. At E-7 min the Lander separates from the Cruise Stage and turns to the entry attitude.

Peak heating and deceleration occur during ballistic hypersonic flight. Despite a slightly higher entry velocity than Phoenix, heating and deceleration loads are within the capability of the Phoenix design. InSight is 3-axis controlled during the hypersonic phase, but attitude control deadbands are set wide to avoid unnecessary thruster activity for the aerodynamically stable entry vehicle.

Parachute deployment occurs when the entry vehicle has decelerated to low supersonic speeds. The heatshield is jettisoned 15 sec after the parachute is deployed, allowing time to damp parachute-induced attitude oscillations and ensuring a clean separation. Ten seconds later the landing legs deploy; this provides enough time for the heatshield to separate completely and clear the vehicle’s flight path. The landing legs deploy sequentially at 0.5 sec intervals, and each deployment completes within 0.25 sec.

The landing radar begins searching for the ground 30 sec after the parachute is deployed, and when within range it provides the altitude and velocity data needed to determine optimal backshell-separation altitude.

Terminal descent consists of 0.5 sec free fall to clear the backshell, after which the descent engines begin firing until touchdown Engine shutdown occurs within 0.25 sec of touchdown detection and represents the completion of the EDL portion of the mission.

2.2.3 Instrument Deployment

On the day that InSight lands (Sol 0) the first goal is to achieve a power positive state of the landed system. The solar arrays autonomously deploy and all systems not required for surface operations power off.

The landed mission activities begin on Sol 1 and initially consist of the Instrument Deployment Phase during which the SEIS, WTS and HP3 elements are deployed to the surface and commissioned for science operations. Initial activities after landing also include monitoring the spacecraft systems, checking out the instruments and IDS, and characterizing the landed environment and deployment work-space. These activities complete after Sol 4. Refer to Figure 3: Deployment Timeline [7].

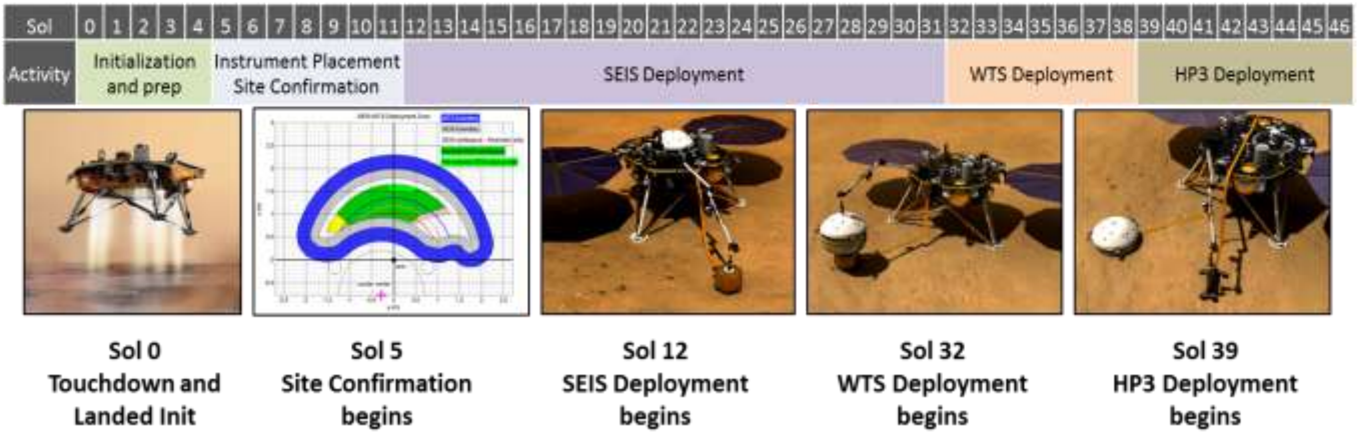

Figure 3: Deployment Timeline

The joint JPL/LM flight team as well as the international partners for science and instrument operations support instrument deployment and commissioning activities. The sequence of activities after initialization is complete is to confirm the placement locations for the SEIS and HP3 instruments a then to deploy those instruments. This activity is the first time that instruments will be robotically placed onto the surface of another planet and represents an area of significant development work for InSight.

During the Site confirmation process, the Instrument Deployment Camera (IDC) will image the workspace and ground operators will determine if the pre-selected deployment sites for SEIS and HP3 are acceptable. If they are not acceptable, due to rocks or other environmental impediments, new sites will be selected within the workspace that can be reached with the robotic arm. Once acceptable sites are defined, the next sub-phase of the deployment phase begins.

The SEIS is the first element which is deployed onto the surface. The process used is to first grapple the SEIS lift element with the grapple element on the robotic arm, confirm that the SEIS is grappled, then deploy the SEIS to the defined location within the workspace. The SEIS will then determine if the location is acceptable before the arm releases the SEIS. The SEIS is then imaged to verify proper deployment has been achieved before the SEIS team begins instrument initial commissioning activities to confirm that the deployment will be sufficient to achieve science objectives. Once this is completed, the team will move to the next step of the deployment process.

After SEIS is successfully deployed, the Wind and Thermal Shield (WTS) will be deployed over the SEIS instrument. The WTS is necessary to complete SEIS installation by providing a protective cover from the external environment to the SEIS sensor. The process steps are to grapple the WTS grapple element, deploy it over SEIS, conform a non-interfering deployment and then release the WTS. Once this step is completed, the final installation imaging occurs before moving to the next deployment step.

The HP3 instrument is the last element to be deployed.it follows a similar set of process steps as the SEIS instrument. However, once the acceptability of the site has been confirmed for the HP3, the next step in the process is to start the penetration of the mole into the Martian regolith. The mole is designed to penetrate up to 5 meters into the Mars regolith and this process starts right after deployment and continues for several weeks.

2.2.4 Surface Science Operations

Operations during the long-term science monitoring phase are simple, repetitive, and robust. During a typical sol, the Lander wakes for ∼25 minutes every ∼3 hours to perform a health check and collect housekeeping and science data. During two of the daily wake cycles, the Lander stays awake for an additional 30 minutes to select and transfer data for radiation, then relay them to the available orbital assets. The Lander provides continuous power to SEIS and HP3 throughout this phase, and once or twice a week powers on the RISE Small Deep Space Transponder (SDST) for a one-hour measurement session with the DSN. This activity continues for the full Martian year after landing [8].

2.3 PAYLOAD DESCRIPTION

The payload for InSight was developed to meet the baseline science requirements. The requirements are met by three investigations: a seismometer (SEIS); a heat flow and physical properties probe (HP3); and a radio science investigation (RISE) conducted with the x-band telecom system. SEIS and HP3 are placed on the surface with an instrument- deployment system (IDS) comprising an arm (IDA), deployment camera (IDC), and context camera (ICC). SEIS and HP3 collect data autonomously over one Mars year. The Deep Space Network tracks RISE's X-band transponder signal one to two hours per week. Additional the Axillary Payload Sensor Suite (APSS) onboard the lander provides support to the SEIS instrument through

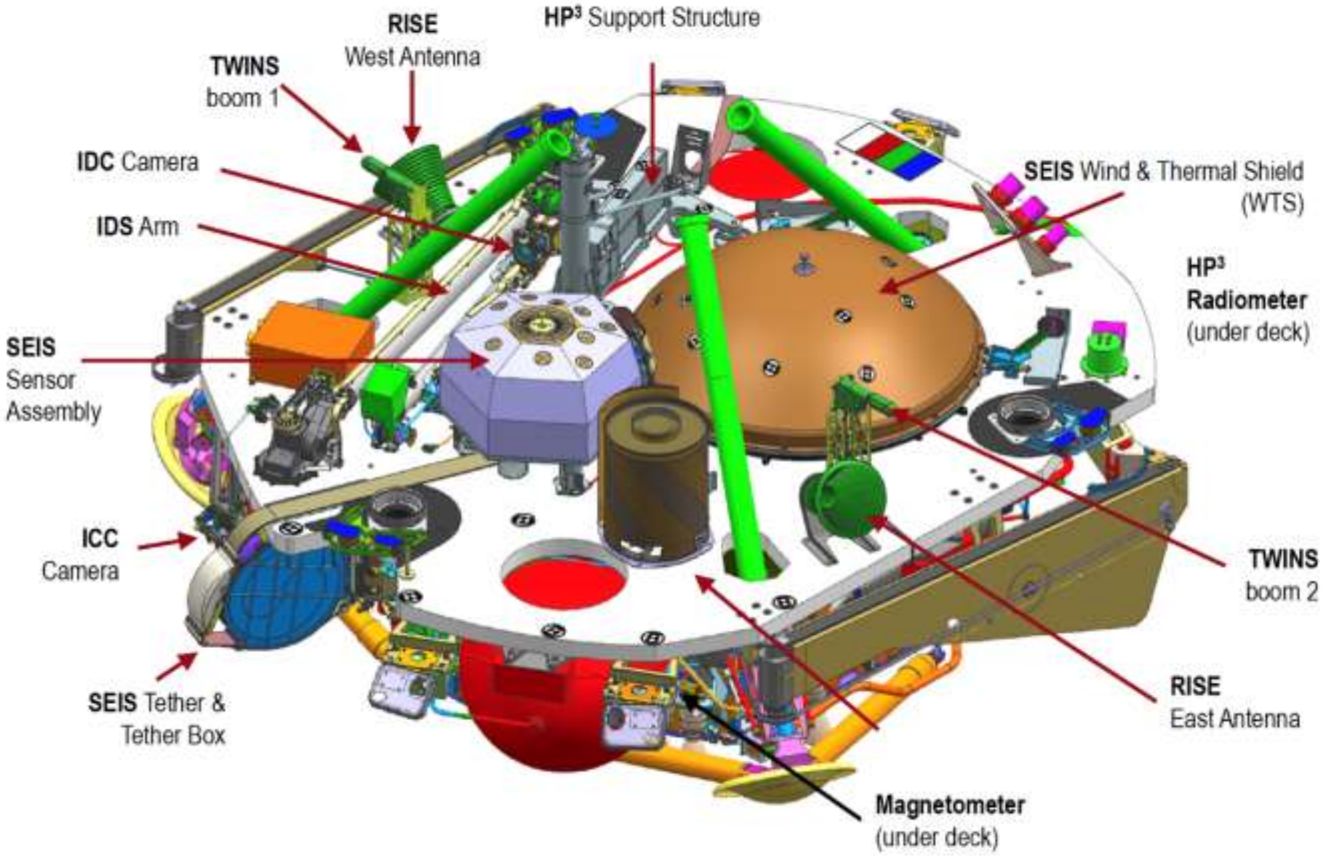

Figure 4: InSight Payload Configuration

monitoring of the Martian environment, which can influence the SEIS measurement [9].

2.3.1 SEIS

An international consortium develops the Seismic Experiment for Interior Structure (SEIS) instrument for the InSight mission (Table 1: Payload Contributions). CNES manages each of the deliveries from the contributors and performs the final integration and test of the instrument prior to delivery to spacecraft level integration (ATLO) [10].

The SEIS consists of two independent, 3-axis seismometers with different underlying technologies: a very broad band (VBB) oblique seismometer contained within a pressure vessel (sphere) and a solid-state short-period (SP) seismometer. The SP sensor provides partial measurement redundancy and extends the high-frequency measurement capability of the SEIS. Both sensor sets are mounted on the precision leveling structure (LVL). The Leveling structure is then encapsulated within a thermal blanketing structure (RWEB) to provide a secondary layer of thermal protection for sensor elements. All of these pieces together comprise the Sensor Assembly (SA), which is the portion of SEIS that is deployed to the Martian surface. The SA is connected to the electronics box (EBox) within the lander by a multi-layer flexible tether.

The VBB sensors are isolated from the martian environment utilizing three layers of protection. This isolation is critical to achieving the high performance measurements required to achieve the baseline science. The main environmental factor needing isolation is temperature fluctuations and the secondary factor is wind disturbances. Temperature fluctuations at the sensor assembly are first attenuated by the pressure vessel that the VBBs are enclosed within. The RWEB around both the VBBs and the SP provides the secondary level of protection. The final layer of protection for both temperature and wind noise is the Wind and Thermal Shield (WTS). During deployment the WTS is placed over the SEIS sensor assembly.

SEIS VBB. The VBB displacement transducers are a trio of orthogonal, inverted pendula stabilized with a leaf spring and tuned for Mars gravity; they are packaged in an evacuated sphere with internal temperature compensation. A differential capacitive sensor detects movement of the housing relative to the pendula, which are continuously centered by a magnetic-coil actuator using a force-feedback system.

SEIS SP: The SP is a MEMS device consisting of a triad of monolithic in-plane silicon proof mass/folded-cantilever suspensions, with electroplated coils and capacitive sensors

Element	Lead Center
SEIS Instrument & Electronics	CNES
VBB & sphere & cradle	iPGP, CNES
SP	Oxford, Imp. College
LVL	MPS
E-box	ETH Z
Wind/thermal shield	JPL
Tether & tether box	JPL
Flight software	JPL
HP^3 Instrument & Electronics	DLR
APSS	JPL
Temp, wind sensors (TWINS)	CAB
Pressure sensor & electronics	JPL/Tavis
Magnetometer & electronics	UCLA
Pressure inlet	JPL
Instrument Deployment System	JPL
Instrument Deployment Arm (IDA)	JPL
Instrument Deployment & Context Cameras (IDC/ICC)	JPL
End-effector (grapple) (EE)	JPL
RISE Experiment	JPL/LM

Table 1: Payload Contributions

driving analog feedback circuits. The SP is not required for SEIS to meet its baseline science requirements. It provides partial redundancy to the VBB sensor and also covers a different spectra of seismic waves.

SEIS LVL. Once the SEIS is placed on Mars, the LVL provides the capability to compensate for local terrain slopes (≤13° off horizontal at the landing site) while providing mechanical coupling to the ground with minimal signal distortion.

SEIS EBox. The EBox provides conditioned power to the sensor assembly, acquires the seismometer signals, provides feedback, and integrates environmental and housekeeping sensor data into the data stream. It is also used to issue commands to the VBBs, SPs and LVL subassemblies.

2.3.2 RISE

InSight's Rotation and Interior Structure Experiment (RISE) measures the rotation of Mars to high precision by employing two-way X-band carrier-signal tracking between the Lander and Earth, with two to four ~1 hr tracking passes per week. The Lander X-band transponder receives a carrier signal from an Earth DSN tracking station and transmits a signal back to the tracking station. The station measures the Doppler frequency shift of the round-trip signal, which is proportional to the Lander velocity along the line of sight (**Error! Reference source not found.**). Tracking for extended periods in the proper geometry resolves annual and semiannual precession and nutation signatures, which are a small perturbation on the Mars spin-axis direction [2].

2.3.3 HP3

The Heat Flow and Physical Properties Package (HP3) measures the heat flux coming from the interior of Mars at the landing site of the InSight mission. Heat flow is a major constraint on models of the current state of Mars' interior and is key to understanding the evolution of terrestrial planets in general [11].

HP3 achieves this by penetrating up to 5 meters into the Martian subsurface with a self-contained hammering apparatus called the 'mole'. The mole science tether, which trails the actual mole, is configured with temperature sensors. As the mole penetrates the regolith, the sensors measure the temperature conductivity of the surrounding regolith as it penetrates (at roughly 50 cm intervals).

The HP3 is equipped with a tether length monitor and an accelerometer to measure tilt for the determination of the mole depth and penetration path. As the mole penetrates, it pulls a tether behind it that both provides power/data to/from the mole, but is also instrumented with temperature sensors. Following the end of the penetration phase (approximately 30 sols of intermittent operation), these temperature sensors remain in the subsurface and monitor the temperature over a vertical profile for 1 Mars year. Integration of the data from each of these sensors over time shows the temperature flux along the mole borehole.

HP3 consists of an electro-mechanical hammering mechanism, the mole that penetrates below the Martian surface and contains resistive heaters/thermometers for the active thermal-conductivity measurement as well as tilt sensors to determine its trajectory through the ground. It pulls behind it the Science Tether, with temperature sensors to measure the thermal gradient in the subsurface. A support structure houses both the mole and the Science Tether prior to ground penetration, contains the Tether Length Monitor to determine the amount of Science Tether deployed. An Engineering Tether connects the deployed instrument to its Back-End Electronics (BEE) located in the Lander There is also a deck-mounted radiometer that measures surface brightness temperature.

3. 2016 LAUNCH OPPORTUNITY

InSight was originally planned to launch in March of 2016. All of the project elements had been delivered to the LM ATLO team, integrated onto the spacecraft, thoroughly tested and had been shipped to the launch pad. However the SEIS Flight Model (FM) was never delivered to ATLO due to a major technical issue. This section will describe the issue and the recovery efforts undertaken by the project after the 2016 launch scrub to reduce risk for a 2018 launch opportunity.

3.1 MAJOR ISSUE

3.1.1 SEIS Development Background

The SEIS instrument is a highly complex device build with delicate components in an artisanal manner to produce ultra-sensitive signals. The VBBs are designed to be sensitive enough to measure displacements that are equivalent to half the radius of a hydrogen atom. Producing these types of devices proved to be much more difficult than anyone on the team anticipated.

3.1.2 SEIS Early Development Issues

Originally, the VBBs and the sphere were to be built by a French Subcontractor, with oversight from Insitut de Physique du Globe de Paris (IPGP) with funding from CNES and minimal interaction with JPL. However, in July 2014, just before the planned delivery of the VBBs for integration into the Sphere a major issue with contamination was uncovered which caused a change in the roles of the entities.

Once the delivery of the VBBs to the next level of integration was uncovered, a tiger team was formed with member from each of the four organizations. In the process of this investigation not only was the source of the problem for the contamination found, but several other significant issues also were uncovered. So many in fact, that a partial redesign of the VBBs was required. This process was initiated in the Fall of 2014 and required a complete disassembly of the existing VBBs, manufacturing of new components, new processes and procedures for the assembly, and a new test program. There was also a change in the relationship of the parties involved in the development with JPL taking a more direct role in the hands on design, build, assembly and test process and CNES taking more involvement in the day-to-day management of the subcontractor.

Importantly the focus of the SEIS team and the payload management was on VBB development as it had become extremely critical to the SEIS delivery schedule and the overall project schedule. The planned delivery date for SEIS to ATLO was a constantly moving target, but was planned for summer of 2015 [12].

There were many layers of technical issues that the joint team overcame in completing the VBBs. However, they ultimately delivered three flight VBBs for integration into the flight Sphere.

3.1.3 SEIS Sphere Issue

The correct operation of the VBBs require that they are located within an evacuated vessel usually referred to as the "sphere". The sphere provides isolations for external thermal fluctuations, internal particles creating Brownian noise, and contaminants. Without these protections, the SEIS instrument noise is too high to extract the desired signal level [13].

Figure 5: QM Sphere Collapse

During the same time period in which there was much focus on the VBBs and their myriad of issues, the sphere was moving slowly along with little attention from the team. A Qualification Model (QM) of the sphere was manufactured, but was waiting for a VBB of some pedigree to be available for installation into the QM for test purposes. However, because there was so much development work on going with the VBBs, there were no VBBs available for use with the QM sphere until the flight VBB development work was nearly complete. This delayed the availability until March of 2015. Shortly after the installation of the VBB, the sphere was evacuated and a major failure occurred in early April (Figure 5: QM Sphere Collapse).

The failure of the QM Sphere was due to an incorrectly designed hemisphere, which lacked sufficient structural rigidity. The subcontractor designing the sphere had not done a buckling analysis on the design. After the fact analysis showed a negative margin which led to the collapse [14].

Once the reason for the collapse was understood, the design, analysis, manufacture and test for the replacement hemispheres was handed off to JPL to complete for the flight and QM sphere. These were completed in time for the flight sphere, but the QM again took a second priority and was not built up before the FM.

Once the FM unit was built up with the newly designed more robust hemispheres it entered into the sphere level test program. The test program went fairly well, but emphasized tests of the VBB, not as much of the full sphere system. This was largely due to having all of the rest of the SEIS instrument already at CNES waiting for the sphere to arrive. Because of this, the thermal testing was deferred to the system level. Once the thermal test was completed in August 2015, a leak was detected in the sphere which was eventually isolated to the feedthrough connector used for one of the VBBs.

The joint SEIS Tiger Team attempted multiple fixes to the leaky connector, but were ultimately not able to fix the leak in time to get to the launch pad in time for a 2016 launch.

Missed Opportunities

Not having a QM did not allow for an early detection of the issue with leaky connectors that ultimately caused the delay of the 2016 launch However, the collapse of the QM Sphere was just one of several missed opportunities to detect the faulty connectors.

1. Inadequate procurement specification.
2. Inadequate component level testing
3. No external review of design
4. No assembly (QM) level testing

Any of the above activities, if successfully implemented, would have exposed the issue with the faulty connectors prior to building the FM sphere with these elements.

3.2 RISK REDUCTION PROCESS

Once the 2016 launch opportunity was cancelled, NASA asked the project management for a proposal for a 2018 launch opportunity. The project decided that it was important to not only address the issue with the leaky sphere, but to also address all of the risks that had been accumulated heading into the 2016 launch. The intent was not to try to do something about every risk, but to determine if any of the risks issues either needed to be addressed because they represented an unacceptable risk for a 2018 launch or should be addressed because they could be easily worked with the additional time to the 2018 launch [15].

The InSight Project System Engineer (PSE) led the effort to complete this task with support of the entire project, including the international instrument partners. The process involved first identifying the potential risk items to work and work to go items for a 2018 launch. The list included:

- Assessments of the change of environments caused by the 2018 launch
- Actions needed to be taken to store the hardware and testing to be done before it was stored
- Lifetime reassessments given a 26 month launch delay
- Waivers and problem reports that should be re-examined
- Changes to the system to increase robustness, operability, and lessons learned from the 2016 efforts (ATLO, operations planning, SEIS Tiger Team investigations, etc.)

The list of items identified for discussion and disposition included over 330 items.

The project met with each project element and dispositioned each of these items in a two step fashion. The first meeting was to make a strictly technical assessment without consideration of the programmatic impact. Each item was characterized as Must Fix, High Priority to fix, Medium Priority to Fix, Low Priority to Fix, or No Change Needed. Once all of the items had been dispositioned, the full list could be assessed. Not surprisingly, the available schedule and budget only allowed consideration of Must Fix and High Priority items except for a few cases where the lower priority items required minimal resources to complete.

Once the project completed the technical disposition and programmatic planning for implementation an external review process started. The project first met with the project Standing Review Board (SRB) and independent cost analysts to allow them to investigate the risk reduction process and resultant plan. After this successful review, the project and SRB met with NASA Management to finalize the plan including the new resources required to implement the plan for a 2018 launch. This process concluded in August of 2016 with approval given to proceed to a 2018 launch [16].

3.3 RISK REDUCTION RESULTS

The result of this process was a defined scope, which the project used as a basis to generate a schedule and budget to support a 2018 launch with a lower overall risk.

The key elements identified for the project to work were delivery of a non-leaking SEIS instrument and redesign of the HP3 mole to address late life test issues. There was also work to go defined for operational planning for deployment, and EDL/Navigation design and analysis work to support a 2018 Launch. Other areas on the project also had risk reduction activities, but not of the same work scope as the above elements.

SEIS Risk Reduction

The primary focus for the 2018 risk reduction work was to develop a more robust SEIS Sphere and overall instrument. To that end, the notable elements changed were:

1. Evacuated container (EC AKA sphere) design, analysis, component testing, manufacture and delivery responsibility were moved to JPL.
2. CNES took direct control of the subcontractor contract and added technical oversight
3. Full reviews of new and rebuilt elements
4. Development of a complete set of spares to allow a complete spare instrument to be built.
5. Augmented testing at all levels of assembly to ensure early detection of any technical issues

Additionally as part of the EC development there were several specific risk reduction steps taken. First, for the feedthrough connectors, the project implemented a parallel procurement path with two different vendors each with a different technology. Second, all of the components of the EC were mechanically and thermally qualified at the component level prior to delivery to the EC-level assembly. Third, a full EC mechanical qualification unit was built using the planned flight processes, equipment and personnel and was then tested to the full qualification specification. Finally, the EC team was maintained throughout the delivery of the final FM EC.

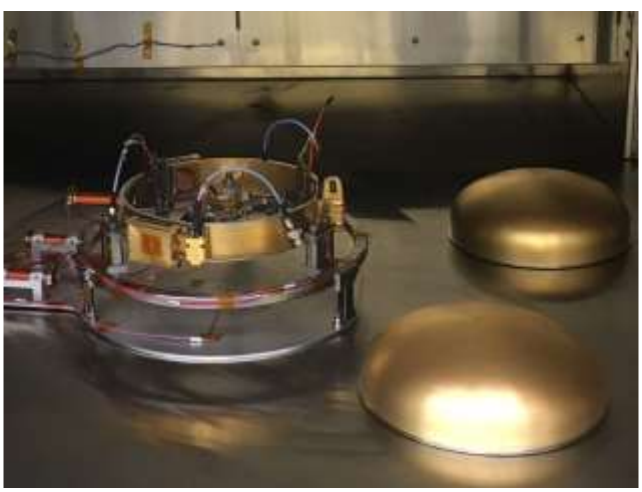

Figure 6: SEIS EC in test

The SEIS Instrument has completed all test steps and has been delivered to ATLO where it is going through the system testing flow.

HP3 Risk Reduction

Late in 2015, the life test of the mole was performed on a flight like unit called the Proto-Flight Equivalent (PFE). This test was expected to last 3X the expected in-flight hammering strokes of the mole, however it only survived slightly more than 1X strokes. The investigation into the failure revealed that the electronic packaging of the mole was not robust [17].

JPL and DLR worked together to re-design the electronic packaging for the mole and then rebuild a new PFE to verify the design and process changes. Once this was completed, a new FM unit was built. This new unit has been delivered and installed on the spacecraft after completing the instrument level test program. It is currently undergoing the system test flow in ATLO

4. CURRENT PROJECT STATUS

The risk reduction activities defined in 2016 have completed. The project currently is performing system level testing in ATLO and preparing for the operational phase of the project heading towards a 2018 launch.

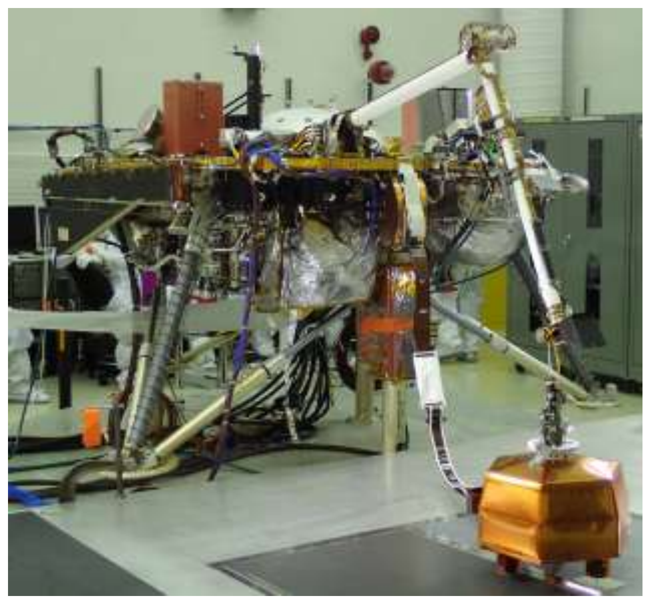

Figure 7: SEIS deployment in ATLO

5. CONCLUSION

The Risk Reduction process used by the project was successful in identifying accumulated risks leading up to the 2016 launch as well as key areas for work to go. Selection of the risk areas to mitigate and execution of those mitigation plans has positioned the project well for the 2018 launch opportunity.

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[17] HP3 Redesign Critical Design Review, August 24, 2016

BIOGRAPHY

Tom Hoffman *Project Manager of the InSight project at Jet Propulsion Laboratory, California Institute of Technology. InSight is the next US lander mission to Mars. Formerly Deputy Project Manager of the GRAIL project which gravity mapped the moon. Has worked on several successful JPL flight and technology programs including Voyager, Cassini, STARDUST, and Mars Exploration Rovers. Specialties include Project Management, Avionics System Engineering, Computer Architecture, and Fault Protection.*